Kansas Agricultural Experiment Station Research Reports

January 2015

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Summary

The 3-sieve particle size analysis method was developed to estimate the particle size of ground grain within feed mills without the time and expense required for a 12-sieve analysis. The 3-sieve method is more simplistic because it is hand-shaken and uses fewer sieves but has drawbacks because it is not as precise as the 12-sieve method. Because shaking is not automated, technician variation may impact results. Furthermore, the accuracy of the original 3-sieve method has been questioned because the method was developed for corn between 400 to 1,200 μm, and the industry now grinds various grains more finely. Some variations, such as changing the top sieve to a smaller diameter hole or using flow agent, may help improve its accuracy. In this instance, 420 grain samples were used to determine the impact of top sieve size, grain type, technician, and flow agent on the ability of a 3-sieve analytical method to accurately predict the mean particle size determined by a standardized 12-sieve method. The experiment was a $3 \times 2 \times 2 \times 3$ factorial with three technicians, two sieve sizes (U.S. No. 12 vs. 16 sieve as the top sieve), flow agent (0 vs. 0.5 g), and three grain types (corn, sorghum, or wheat). Prior to the experiment, all samples were analyzed according to the standard ASAE S319.4 method using a 12-sieve stack with a 15-min tap time and 1 g of flow agent. Linear regression was used to develop individual equations to predict the mean particle size for each of the 3-sieve methods compared to the standard 12-sieve method, and the GLIMMIX procedure of SAS was used to evaluate the impact main effects and interactions on prediction accuracy. All interactions were removed from the model due to insignificance ($P > 0.10$). Technician, screen size, and flow agent did not affect the accuracy of the prediction equations. Grain was the only main effect of significance ($P < 0.05$), where the prediction equation overestimated the particle size of wheat by approximately 15 μm and underestimated the particle size of corn by approximately 12 μm. While statistically significant, these variations were deemed to be sufficiently accurate for the 3-sieve method, and separate equations for each grain type were not warranted to retain the simplicity of the method. In summary, technician, sieve size, grain type, and the use of flow agent did not greatly affect the accuracy of the 3-sieve

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particle size analytical method, so the original method was concluded to be accurate and the preferred method.

Key words: 3-sieve, analysis, grain, method, particle size

Introduction

Reducing the particle size of cereal grains is understood to improve feed efficiency in swine and poultry. Therefore, the accurate determination of particle size, or mean diameter, of cereal grains is important to feed manufacturers and producers. A standardized method for determining the geometric mean and standard deviation of particle size was first reported in 1968 and was most recently updated in 2012. The standard method uses 12 or 13 sieves, an automated machine to tap and rotate the sieve stack for 10 or 15 min, and sometimes uses a flow agent to facilitate particle dispersal during the shaking process. This standard method requires equipment that is expensive to purchase and maintain, and it can be time consuming. For that reason, feed manufacturers may use a 3-sieve method to predict approximate mean particle size in the mill and validate their findings with routine testing using the standard method.

The 3-sieve method was originally developed by Baldridge et al. (2001)[3] to quickly predict the particle size of corn between 400 and 1,200 μm. As the industry evolves to further reduce particle size of grain, it is necessary to validate if the existing 3-sieve method remains accurate for particle sizes of various grains ground smaller than 400 μm. Furthermore, it is important to evaluate if different interventions, such as the use of different sieve sizes, flow agent, or a single technician, can further improve the ability of the 3-sieve method to predict the mean particle size according to the standard method. The objective of this experiment was to determine the impact of top sieve size, grain type, technician, and agent on the ability of a 3-sieve analytical method originally developed by Baldridge et al. (2001)[3] to accurately predict the mean particle size determined by a standardized 12-sieve method.

Procedures

The original 3-sieve method developed by Baldridge et al. (2001)[3] utilizes a U.S. No. 12, 30, and 50 screen plus a lid and receiving pan with a caruncle brush and rubber ball placed on the U.S. No. 30 screen; and two brushes and one ball placed on the U.S. No. 50 screen to facilitate particle movement through the sieve. The weights of empty sieves and the pan are recorded, the sieves stacked in order by descending screen size and placed on top of the receiving pan. Fifty grams of ground corn is weighed and placed on the top sieve, a lid is placed on top of the sieve stack, and the stack is shaken from side to side by hand for 90-s. The weight of each sieve and receiving pan is then recorded, and the percentage of material caught in each sieve is utilized to calculate the predicted particle size using the equation: Particle Size, μm = $(18.832 \times A) + (10.870 \times B) + (1.1827 \times C) - 149.978$, with A, B, and C representing the percentage of sample on the U.S. No. 12, 30, and 50 screens, respectively.

[3] Baldridge, A., T. Stainbrook, J. Woodworth, M. D. Tokach, J. L. Nelssen, and R. D. Goodband. 2001. A comparison of different particle size analysis techniques. In: Kansas State University Swine Day 2001 Report of Progress. SRP880. Kansas State Univ., Manhattan. p. 138-141.

Field reports and personal observations noted the potential areas of highest variability affecting the accuracy of the 3-sieve method were person-to-person variability in shaking, grain type, and grinding fineness. In fact, it was noticed that nearly all the material sifted through the U.S. No. 12 screen when grain was ground below 600 μm, which presumably would impact the accuracy of the 3-sieve method for smaller particle sizes. Therefore, we deemed it important to evaluate a 3-sieve stack with a different top sieve to catch a greater proportion of material. Finally, it was challenging for some of the very finely ground material to sift through the smallest sieve when shaken by hand. A flow agent, such as fumed silica, helps prevent this occurrence in the standardized method and may be applicable to the 3-sieve method. Thus, a 3 × 2 × 2 × 3 factorial arrangement of treatments was designed with three technicians, two sieve sizes (U.S. No. 12 vs. U.S. No. 16 sieve as the top sieve), flow agent (0 vs. 0.5 g), and three grain types (corn, sorghum, or wheat).

Technicians were instructed to shake the 3-sieve stack by hand from side to side for 90-s, according to Baldridge et al. (2001)[3] The U.S. No. 16 (1.19 mm) sieve was chosen as a replacement for the U.S. No. 12 sieve (1.68 mm) by evaluating the screens that caught the greatest proportion of grain on the 12-sieve stack. Finally, 0.5 g of fumed silica was chosen as a flow agent based on the proportion of flow agent used in the standard method, which is 1 g of flow agent per 100 g of ground grain. Prior to the experiment, all samples were analyzed according to the standard ANSI/ASAE S319.4[4] method using a 12-sieve stack with a 15-min tap time (W. S. Tyler RX-30 Ro-Tap Shaker, Mentor, OH) and 1 g of flow agent. A total of 420 samples of ground grain were used in these analyses. This included 140 samples each of ground corn, sorghum, and wheat that were ground by either a hammermill or roller mill, with 70 samples per mill per grain type.

Statistical analysis

Linear regression by the REG procedure of SAS was used to develop individual equations to predict the mean particle size for each of the 3-sieve methods compared to the standard 12-sieve method, and the GLIMMIX procedure of SAS was used to evaluate the main effects and interactions on prediction accuracy with mill type serving as a random effect. All interactions were removed from the model due to insignificance ($P > 0.10$).

Results

Results are depicted as residuals between the predicted particle size according to the 3-sieve method and the standard 12-sieve method. Technician, top screen size, and flow agent did not impact the accuracy of the 3-sieve method (Table 1). The variability within technician was greater than that among technicians, with a maximum mean deviation of 5.1 μm from the 12-sieve method.

Likewise, there was little variability when evaluating the 3-sieve method with either the U.S. No. 12 or U.S. No. 16 sieve as the top screen. Even though it did not catch much material, the U.S. No. 12 sieve was within an average of 0.15 μm of accurately predicting the particle size according to the standard method. Because of the accuracy of the

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[4] ASAE. 2009. Method of determining and expressing fineness of feed materials by sieving. ASAE Standard S319.4. American Society of Agricultural and Biological Engineers, St. Joseph, MI.

original 3-sieve method, no additional improvement was observed when 0.5 g of fumed silica was included as a flow agent. The flow agent resulted in the 3-sieve method under-predicting the mean particle size by an average of 2.4 μm, compared to overpredicting the particle size by 4.1 μm without the flow agent.

In contrast, the type of grain used in the 3-sieve method impacted its accuracy. The original 3-sieve method routinely underpredicted the particle size of corn by an average of 12.3 μm and overpredicted the particle size of wheat by an average of 14.7 μm; while sorghum was, on average, within 0.1 μm of the 12-sieve standard method ($P < 0.05$). While the 3-sieve method should be able to accurately predict the mean particle size, it is possible that the change of particle shape alters its flow through the 3-sieve stack during shaking.

Discussion

There appears to be little technician-to-technician variability when personnel are instructed to shake sieves for 90 s. Baldridge et al. (2001)[3] indicated that a 90-s shake time optimized the relationship between efficiency and accuracy, with 1.0 g less sample passing through the screens when shaken for 60 s and only 0.3 g more material passing through the screens when shaken for 120 s. The lack of flow agent effect is not surprising, given that the original 3-sieve method was accurate. However, Stark and Chewning (2012)[5] demonstrated that analyzing samples without a flow agent could overestimate the particle size and underestimate the distribution of the particles of a sample. We recognize that, due to its significance, it is statistically appropriate to have a separate regression equation for each grain type. However, the true intent of the 3-sieve method is to accurately and easily predict the mean particle size of a ground grain compared to a 12-sieve standardized method. It is our conclusion that the robustness of a single 3-sieve equation to predict the particle size of three types of grains to within 15 μm of a standard 12-sieve stack is a more valuable industry tool than three separate regression equations for each grain. However, we recognize that this conclusion limits the average accuracy of the equation.

In summary, the original 3-sieve particle size analysis method developed by Baldridge et al. (2001)[3] using U.S. No. 12, 30, and 50 sieves accurately predicts the particle size of ground corn, sorghum, and wheat to within 15 μm of the 12-sieve standard method without the use of flow agent and amongst the tested technicians. It remains a recognized, useful, and accurate way to predict the particle size of ground grain in a feed mill without the expense and time required for the standard method, and this experiment proves its robustness for three grain types and from 200 to 900 μm. Still, the 3-sieve method should be validated at least monthly by an equally representative sample analyzed according to the 12-sieve standard to verify procedures and accuracy.

[5] Stark, C., and C. Chewning. 2012. The effect of sieve agitators and dispersing agent on the method of determining and expressing fineness of feed materials by sieving. Animal Production Science. 52(1): 69-72.

Table 1. Residual particle size fixed effects[1]

Item	Residual between the 3- and 12-sieve standard, μm	SEM	P =
Technician		6.035	0.401
1	5.08		
2	-0.97		
3	-1.62		
Top sieve hole diameter		7.432	0.978
U.S. No. 12 (1.68 mm)	-0.14		
U.S. No. 16 (1.19 mm)	1.8		
Flow agent		4.956	0.625
Yes	-2.43		
No	4.08		
Grain type		6.011	0.041
Corn	-12.27		
Sorghum	0.06		
Wheat	14.70		

[1]A total of 420 samples were analyzed in a 3 × 2 × 2 × 3 factorial with three technicians, three sieve sizes, with or without flow agent (0.5 g fumed silica), and three grain types. Prior to the experiment, all samples were analyzed according to the standard ANSI/ASAE S319.4 method using a 12-sieve stack with a 15-minute tap time and 1 g of flow agent. Linear regression was used to develop individual equations to predict the mean particle size for each of the 3-sieve methods compared to the standard 12-sieve method.